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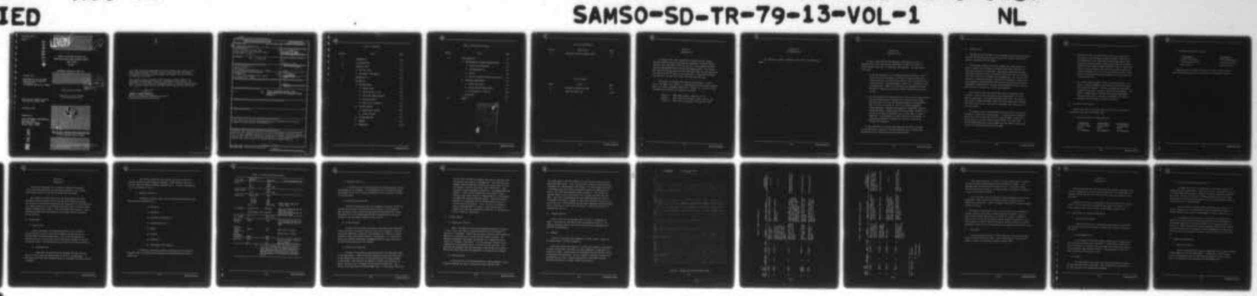

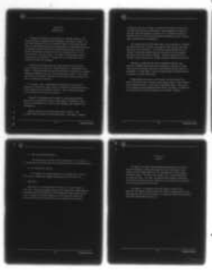

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(REFERENCE VOLUMES II AND III)

Prepared for:

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This final report was submitted by Texas Instruments Inc, Dallas, Texas, under Contract F04701-75-C-0181, with the Space and Missile Systems Organization, Air Force Systems Command, Los Angeles Air Force Station, Los Angeles, California.

This report has been reviewed by the Information Office (OIS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations. This technical report has been reviewed and is approved for publication.

JOSEPH A. STRADA, LCDR, USN
Director of Navigation Equipment & Avionics
Navstar Global Positioning System

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Describes Texas Instrument's efforts to design and develop an alternate Manpack/Vehicular User Equipment (MVUE) set for use in the concept validation phase of GPS. Volume I summarizes design-to-cost goals and results; production engineering program, and field test reliability information. Includes maintainability analysis and fault isolation to achieve mean-time-to-repair goals.

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SECTION I
INTRODUCTION

In June of 1975, Texas Instruments Incorporated was awarded Contract F04701-75-C-0181 to design and develop an alternate Manpack/ Vehicular User Equipment (MVUE) set for use in the Concept Validation phase of the NAVSTAR Global Positioning System program. The contract and specification required a militarized system with maximum commonality and legacy to other classes of user equipment. Extensive performance testing, both in-plant and in the field, was also required.

This report is produced and submitted as Volumes I, II, and III of "The MVUE Final Reports" in accordance with Contract Data Requirements List (CDRL), Sequence Number A003. Volumes IV, V, and VI of the "The MVUE Final Reports" are defined as follows:

Volume IV	MVUE Legacy Report, SOW Para. 4.1.5
Volume V	MVUE In-Plant Test Report, CDRL Item No. A017
Volume VI	MVUE Field Test Report, CDRL Item No. A019

SECTION II
SET DESCRIPTION

This section is bound in Volumes II and III of this MVUE Final Report.

SECTION III
DESIGN TO COST

In order to optimize the GPS equipment with respect to cost, a Design-to-Cost (DTC) program was established in Phase I to provide a proper balance among cost, performance, and schedule. The major objectives were:

1. TI had the responsibility for developing and executing a plan of action to deliver equipment at or below price goals while continuously working to optimize development costs, production costs, life-cycle costs, equipment weight, reliability, performance, and maintainability. Phase I GPS equipment was designed and implemented with aggressive DTC plans directed towards future program savings.

2. The GPS program DTC process made use of the existing program organization by assigning DTC responsibility consistent with organizational constraints for the GPS system design and development. The TI DTC plan involved all levels of program management, design engineers, manufacturing engineers, integrated logistics support engineers, planning and control personnel, producibility personnel, production engineers plus various other TI support personnel. As an example of support personnel involvement, TI purchasing personnel encouraged our vendors to develop and maintain DTC programs.

TI was committed to an active and productive DTC effort throughout the GPS Phase I programs life-cycle and continued to develop cost savings within the constraints of future GPS business.

A. GPS DTC CYCLE

The DTC plan for GPS Phase I was submitted previously and contained the detailed DTC cycle flow which explained the various procedures TI used to incorporate DTC philosophy.

The drawings resulting from the hardware and system design were used to prepare cost estimates to establish the labor and material required to produce the equipment. Both project personnel and other groups contributed to the cost estimates which started with the lowest level part and built up through the top assemblies. The manufacturing engineers, purchasing personnel, producibility engineers, shop supervisors, assembly methods personnel and quality assurance engineers made independent assessments for the cost estimates based on their previous experience with the same or similar type equipment.

A DTC program took the current phase labor and material cost estimates using various learning curves projected the cost in production quantities. The program provided direct labor and material costs and also added overhead, rework and other costs such as general and administrative costs and profit to determine the production unit price estimates.

The production cost estimates derived using the DTC program were compared to direct cost target budgets. If the estimated production costs were equal or less than the cost target budgets, further DTC actions were solicited in order to make further cost reductions. If the estimated production costs exceeded the cost target budgets, one or more of the following actions were taken.

1. DTC action items were identified revisions in system hardware design, test equipment, assembly methods, fabrication, test techniques, etc., which when incorporated, would reduce the production cost without allowing the system performance or schedule to fall below minimum acceptable levels. Identification and incorporation of DTC action items were a continuous process throughout the life of the GPS Phase I program. Many revisions identified were very aggressive and were applied to future applications.

2. DTC reports were designed to keep TI design engineers, TI GPS Phase I program management, and SAMSO advised of the current DTC program cost status. The DTC processes were repeated or updated as required or as major impacts were discovered. This dynamic concept made it imperative that program personnel remained committed to an active and productive DTC effort throughout the GPS Phase I program life cycle.

B. GPS PHASE I DTC RESULTS

Specific DTC results from GPS Phase I DTC studies are numerous. Listed below are some of the major ones.

1. Increased Capacity of Memory Modules

First Design	Second Design	Future Design
10 multi-layer boards	4 multi-layer boards	5 multi-layer boards
910 components	364 components	300 components

2. Frequency Synthesizer Changes

First Design	Future Design
2 multi-layer boards	1 multi-layer boards
3 microwave amplifiers	1 microwave amplifier
Analog switch	Digital oscillator

These examples illustrate the effective result of positive real cost savings demonstrated by the DTC effort on GPS Phase I program.

SECTION IV
PRODUCIBILITY

Producibility engineers participated as integral members of the design production engineering team throughout the Phase I program. It was their responsibility to be intimately aware of the design and the plans of the engineers during the design effort and influence the design to the maximum extent possible to ensure that the product was built within the manufacturing operations of the Equipment Group so as to minimize total life-cycle costs. They were in the approval cycle of all drawings to verify their influence and to further ensure that a producible product was designed.

Producibility design guides were made available for particular areas of specialty to assist the design engineers in standardizing the design. The design guides had separate sections for fabrication, assembly, microwave integrated circuits, and printed circuit boards. Each listed the criteria, particularly suited for their shops, that would assist the shops in producing the product.

At an equal level of importance, performance was the criteria necessary to ensure the proper quality, reliability, and maintainability of the product during the Phase I design. These criteria were taken into consideration to ensure minimum cost.

Producibility engineers participated in other design considerations such as strength of material used, weight requirements, stress analysis, microelectronics circuitry and packaging, shop capabilities and capacity.

Specific examples of producibility studies in Phase I are:
A "Common Module" approach was developed early in the Phase I program.

A tradeoff study was initiated to consider the effects of functional partitioning restraints, system costs, system packaging limitations, and user class environments on module size. Although the number of possibilities was infinite, several detailed parameters were listed as major considerations and addressed.

Two common module versions were used. One is housed in a shielded can while the other is an open card used for circuitry not requiring shielding or RF connections. All conform to MIL-STD-1389 dual span modules in width and center-to-center spacing and utilize standard extraction tools for removal purposes. Plans for module evolution included further reductions as further component integration occurred.

Secondly, a producibility study to determine the most cost-effective shielded can approach was performed on soldered on covers, three piece die castings, extrusions, and machined hog-out being the candidates. To meet Phase I cost and schedule goals the machined hog-out proved to be the best choice.

These examples are only a small portion of the producibility effort during the Phase I concept and validation phase in which Producibility Engineering was a vital part of the design team. The producibility objectives were achieved and GPS Phase I equipment is producible for the quantities and rates required in the Phase I contract.

SECTION V

RELIABILITY

This section documents the reliability information obtained while field testing MVUE 01 at Yuma Proving Grounds, Yuma, Arizona. Failure data from this testing is reviewed and discussed.

The reliability support effort for the Manpack/Vehicular User Equipment (MVUE) has been active since the early stages of proposal for contract. Reliability Engineering was responsible for the generation of a parts selection list and reliability design guide, including recommended component stress levels. After the design was complete, a data collection system was established to ensure good reliability growth during testing.

A. DESIGN EFFORT

1. Design Guide

During the design of the Manpack/Vehicular User Equipment, reliability was active in establishing specific guidelines, which were followed by the designing effort. One of the requirements of reliability was to write and deliver to the design engineers a Reliability Design Guide. The design guide consists of the following sections.

a. Derating Rules

Components reliability can be achieved only when the part does not receive stresses beyond those for which it was designed. In most cases, the lower the stresses placed on a component the more reliable it becomes.

The following derating rules define the maximum electrical stresses which the design engineer followed. These derating rules are part of Texas Instruments Standard Procedure 18-2. A copy of the derating rules is attached in Table 1.

b. Component Selection

The design guide also deals with the particular components and some of their characteristics:

- Resistors
- Capacitors
- Discrete Semiconductors
- Integrated Circuits
- Relays
- Switches
- Connectors
- Transformers and Inductors

In addition, each device catagory was broken down by specific component type, its applications discussed, and recommendations made for system use.

Table 1. Reliability Derating Rules

Part Type	Parameter to Derate	Derate to	Other Considerations
Diode	V_R	50%	
	I_O	50%	
	T_J 1/	120° C Max	
Diode, Zener	P_T	50%	
	T_j 1/	120° C Max	
Transistor	BV_{CEO} <20V	80%	
	20-50V	70%	
	50-120V	60%	
	> 120V	80%	Observe safe operating limits (SOA)
	T_j 1/	120° C Max	
IC, Digital	T_{pd} (54 TTL)	Add 40%	Add 0.15 nanosecond per pF additional load
	T_{pd} (Schotky TTL)	Add 20%	Add 0.15 nanosecond per pF additional load.
IC, Linear	T_J	120° C Max	
Resistor, Fixed	Power	50%	Do not exceed maximum hot-spot temperature, MIL-STD-199B
Resistor, Fixed, Metal Film (RNC)	Power	50%	50% of 70° C rating
			80% of 125° C rating
Resistor, Variable	Power	50%	
Capacitor	DCWV	50%	DC bias voltage + AC peak not to exceed
	AC	50%	DCWV for all AC ratings

1/ It is not intended that the 120°C junction rule result in illogical design decisions on power semiconductors. Consult reliability engineering for tradeoff analysis and approval requirements for temperature exceeding 120°C.

2. Preferred Parts List

In conjunction with the design guide, a preferred parts list was distributed to all engineers. The preferred parts list describes those parts whose use will best assure achievement of the contractual reliability obligations.

3. Parts and Drawing Review

During the design activity the responsibile project reliability engineer was included in the drawing review cycle. As the drawings were reviewed by the reliability engineer they were checked for proper documentation, use of established reliability components, contractual obligation and calculated component stress levels.

4. Stress Analysis

A worst case and normal operation stress analysis was performed on each printed wiring board, based on the circuit diagrams. From the stress data obtained, an analysis was performed in an effort to isolate components which were applied wrong or overstressed. If a problem was found, the reliability engineer recommended design changes and worked with the design engineer on the problem.

5. Reliability Prediction

Reliability Engineering conducted reliability predictions based on the MVUE design. These reliability predictions were initiated early in the design effort and were revised periodically to reflect changes in the design. This analysis was made by a failure rate build-up, in which a failure rate is assigned to each relevant piece part. The failure rates were obtained from MIL-HDBK-217B. TI and vendor historical

failure data, engineering judgment and other sources were used for devices not covered in MIL-HDBK-217B. The part rates are summed to provide PWB level predictions; these rates, in turn, are summed to provide LRU and set level predictions. These calculations were performed by means of a TI developed computer program. "PLST," which automatically calculates failure rates and sums them, based on a computerized bill of materials, MIL-HDBK-217B, and environmental inputs. The above analysis resulted in a predicted failure rate expressed in units of "failure per million hours." This, in turn is inverted to yield a predicted MTBF in "hours." The final reliability prediction, which was calculated by PLST prior to system evaluation at Yuma was 1,655 hours.

B. TESTING SUPPORT

1. Board Level Testing

When a printed wiring board has completed assembly, the board is sent to Unit Test where a thorough examination of its electrical operation is performed. Should for any reason a board be found defective, the board is evaluated and the cause of the problem isolated. All defective components are removed and placed in an assembly and test reject part envelope ("Hold Bag"). All the necessary information for traceability of the defective part is written on the Hold Bag. The Hold Bag and component are then delivered to the reliability engineer. Records are kept along with the components to isolate failure trends.

2. System Testing

During testing of the Manpack/Vehicular User Equipment, a data collection system was used to locate and correct problem areas.

The system used on the GPS programs is titled the Reliability Failure Reporting (RFR) system. Also, the Hold Bag is used to capture the bad components for record keeping and storage. This RFR system consists of a multicopy form, which keeps a complete history of a system failure down to the individual component failure analysis. The reliability engineer keeps an up-to-date record of all system failures with this form. Each form is prenumbered for easy record keeping and control. The number of the RFR is entered in the system paperwork at the time of a test failure. The RFR system has been used throughout the GPS programs both in-house and at the Yuma test grounds. A copy of an RFR form is attached as Figure 1.

C. FAILURE ANALYSIS

Table 2 lists all of the MVUE field failures in chronological order. This data was recorded on RFRs as described in Part 3. The symptom, analysis results, and any corrective action associated with each RFR are delineated.

D. SUMMARY

A total of nine RFRs were presented in Table 2 above. These are discussed below in various categories.

There were three RFRs (Items 1, 2, and 8) that refer to occurrences at which failures were indicated, but upon subsequent investigation no failure was found. These events are considered one-time operator errors, as they have not reoccurred. For this reason no corrective actions are warranted at this time. These events were not considered relevant failures and were not included in MTBF calculations.

PROJ. NO. | NO. 050801 | **RELIABILITY FAILURE REPORT (RFR)** | PROJ. NAME

SYSTEM/AC NO.	REF. STA.	DATE	FAILED UNIT	SEQ/SER NO.	REF. DES.	OP. TIME

ORIGINATOR (120)

DESCRIPTION OF SYMPTOM

TEST PROCEDURE NO.	TEST PARAGRAPH NO.	ENVIRONMENTAL COND.	ORIGINATOR NAME

TROUBLESHOOTER

FAILED ASSEMBLY	SEQ. NO.	REF. DES.	PRODUCTION CONTROL	W.O./E.O. NUMBER

DESCRIPTION OF PROBLEM CAUSE AND REPAIR ACTION TAKEN

REJECTED PART DATA	PART NAME	PART NUMBER	PART REF. DES.	SERIAL NO.	DATE	TROUBLESHOOTER NAME

1. TROUBLESHOOT				2. REMOVE				3. REPAIR		4. REPLACE				5. ADJUST				6. FUNCTIONAL TEST			
SYS	WRA	SRA	MEN	WRA	SRA	S SRA	MEN	ITEM	MEN	WRA	SRA	S SRA	MEN	SYS	WRA	SRA	MEN	SYS	WRA	SRA	MEN
HR MIN	HR MIN	HR MIN	NO.	HR MIN	HR MIN	HR MIN	NO.	HR MIN	NO.	HR MIN	HR MIN	HR MIN	NO.	HR MIN	HR MIN	HR MIN	NO.	HR MIN	HR MIN	HR MIN	NO.

160

RELIABILITY (110)

DATE Y M M D D	SYS AC	REFERENCE DESIGNATOR WRA	SRA	S SRA	SS SRA	PART	WRA HRS	WRA SEQ/SER NO.	SRA SEQ NO.	PART NUMBER	REJ STA	FNV	ADD RPT	RPT NO.

FAILURE ANALYSIS (130)

PART D.C.	PART S/N	MFR. CODE	F.A. CODE	R.C.	FAILURE ANALYSIS RESULTS

PART D.C.	PART S/N	MFR. CODE	F.A. CODE	R.C.	FAILURE ANALYSIS RESULTS

DATE	EXAMINED BY

CORRECTIVE ACTION (140)

CCA CAUSE AND CORRECTIVE ACTION

DATE	RELIABILITY

ADD INFO (150)

ADDITIONAL INFORMATION

DATA	RELIABILITY

TI-22085

Figure 1. Reliability Failure Report (RFR)

Table 2. MVUE Field RFR List

Item No.	RFR No.	Relevancy	Date	S/N	Symptom	Repair and Analysis	Corrective Action/Comments
1	47440	N	11/6/78	1	NBM103 had noisy error signal	Replace NBM103; NBM checked OK	———
2	50093	N	1/17/79	1	Elev. profile of volute antenna (MSN 1) gain appears low. Unit had been struck, loose etch suspected	Replace antenna; antenna checked OK	———
3	47443	N	3/7/79	1	PROM problem-PROM 13, Rev. L, caused check sum error in system	Replace PROM 13L. Device initially failed in memory dump; visual inspection revealed no anomalies. Later determined improper PROM blowing technique	Blowing equipment and procedures corrected
4	47446, 50846	R	3/8/79	1	Unable to get out of standby properly	Replace EIOM; 54LS04 loaded down CDU output; part not received	One-time occurrence
5	50751	R	3/13/79	3	MPM 102 would not function, when heated	Replace MPM 102; 9900 suspected to be heat sensitive; part still in evaluation	One-time occurrence

Table 2. MVUE Field RFR List (Continued)

Item No.	RFR No.	Relevancy	Date	S/N	Symptom	Repair and Analysis	Corrective Action/Comments
6	50758	U	3/22/79	1	PWM 01 (part of P.S.) caused excessive current on source lab P.S.	Replace Q3 (2N5884); shorted C-E due to punchthrough - excessive VCE	One-time occurrence may have been caused by high V from source lab P.S.
7	50759	U	3/26/79	1	Receiver status indicated Mode 5 hardware failure	Replace output module 203	Disposition not known
8	50760	N	3/28/79	1	Noisy AGC	Replace WBM 103; no failure found. Input overdriven during jamming calibration for AIL-operator error	———
9	50761	R	5/24/79	3	Receiver failure consistently indicated within 2 min of initialization	Replace RF adaptors-loosened center pins suspected; part not received	Vendor altered design to minimize this failure mode

NOTE: Relevancy: R - Relevant

N - Non-relevant

U - Undetermined

Item 3 was related to a procedural problem, referring to a general problem with blowing programmable read-only memories (PROMs). The equipment used for blowing the PROMs was set at an improper voltage. This has since been corrected. As this problem is procedural in nature, it was not considered relevant.

Two of the RFRs cover occurrences in which relevancy could not be determined: Item 6 states Output Module 203 was replaced, but its disposition was unknown. Item 7 indicates a possibility of test equipment causing a failure.

The remaining three RFRs (Items 4, 5, and 9) cover occurrences considered relevant, since they involved actual part failures. None of these failures have reoccurred and no trend was present. Corrective action, then, is limited to tracking future failures to assure no long-term trends exist and to assure the overall system reliability is within reasonable limits and is achieving reliability growth with operating time.

E. CONCLUSION

For an estimated 350 hours of field operation, the MVUE incurred a total of three relevant failures. The limited nature of the data precludes a conclusion concerning the mature system MTBF.

SECTION VI

MAINTAINABILITY

This section describes the maintainability analysis performed during Phase I to determine the probability of meeting the 15 minute Mean-Time-to-Repair (MTTR) and to fault isolate without the use of external test equipment.

In addition to Phase I requirements, the ultimate MVUE must possess an MTTR of 10 minutes at the organizational level, 20 minutes at the direct support level and 45 minutes at the general support level.

A. MAINTAINABILITY DESIGN CONSIDERATIONS

1. Preventive Maintenance

There are no preventive maintenance requirements for the MVUE. All modules/printed circuit cards are replaceable without adjustment or calibration.

2. Interchangeability

In consonance with DTC/LCC goals, commonality in module design was a primary consideration for the MVUE. In addition to commonality within the MVUE, all modules, with the exception of three, are common to the High Dynamic User Equipment (HDUE). The exceptions are the EIOM, power supply and MIS Interface cards.

3. Access

All subassemblies are easily and quickly accessed by removal of the top and bottom cover assemblies. With exception of the batteries, all SRUs can be quickly removed and replaced.

4. Built-In-Test/Performance Monitoring

An operational test is automatically initiated at power-up to determine system readiness for signal acquisition. Failure of the system to achieve operational status is readily visible to operating personnel by a fault indicator on the CDU. Following signal acquisition, system performance is continuously monitored, as well as system power levels, to verify validity of displayed data.

Fault isolation is accomplished by operator-activated BIT, via the CDU keyboard, and is enhanced by the module commonality concept wherein modules may be quickly interchanged to locate a defective unit.

In addition to the existing BIT and monitoring capabilities, additional software routines are being developed to provide operator/maintenance personnel with greater flexibility in isolating system malfunctions. These routines significantly enhanced testability of the MVUE by providing additional operator-activated CDU commands to probe system functions and permit operator monitoring of signal acquisition and lock-on.

B. SUGGESTED IMPROVEMENTS

1. Master Oscillator

Oscillator stabilization time, although well within specifications, is detrimental to the MTTR requirement. A reduction in stabilization time is a design goal and will facilitate achievement of the ultimate MTTR of 10 minutes at the organizational maintenance level.

2. Battery Removal/Replacement

The elimination of cables and the requirement for a screwdriver to remove and replace batteries would improve maintainability considerations.

3. RF Preamplifier Testing

BIT signals are injected behind the RF preamplifier, leaving this section untested and thereby increasing fault isolation time.

C. CONCLUSION

Attainment of the specified MTTR for Phase I is questionable at this time. The primary reason being the time required for system checkout following corrective maintenance (13.6 minutes oscillator stabilization time). However, oscillator redesign will alleviate the problem and ultimate maintainability specifications are expected to be achieved.

SECTION VII
SUMMARY

This MVUE Final Report has documented the technology, both hardware and software, and the philosophy that Texas Instruments implemented in their Manpack/Vehicular User Equipment for the GPS concept validation phase. The overall set as well as its individual modules has been explained. The Texas Instruments MVUE concepts, techniques, and results of design-to-cost, producibility, reliability, and maintainability have been put forth as well.

This report, in conjunction with the Legacy, In-Plant Test, and Field Test Reports, demonstrates that Texas Instruments has met and improved upon the letter and the spirit of Contract F04701-75-C-0181 with their MVUE development and testing.